

# PROBING PHYSICS BEYOND THE SM AT TEVATRON

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## Abstract

Tevatron Experiments: CDF and DØ collected during October 1992 and February 1996 (Run I) a data sample of roughly  $120 \text{ pb}^{-1}$   $p\bar{p}$  collisions at a center of mass energy  $\sqrt{s} = 1.8 \text{ TeV}$ . A large variety of physical studies have been performed using these data. Current paper reviews last results obtained searching for physics beyond the Standard Model. Direct Supersymmetry (SUSY) searches are not part of this review.

## 1 Introduction

In this paper we review results obtained recently by CDF and DØ collaborations in the field of non-SUSY searches for new phenomena. The analysis described below are based on Run I Tevatron data ( $\sim 120 \text{ pb}^{-1}$ ).

Detailed description of Run I CDF and DØ detectors can be found in the following reference [1].

## 2 Search for Large Extra Dimensions

The Standard Model (SM) has proved to be enormously successful in providing a description of particle physics up to energy scales of several hundred GeV as probed by current experiments [2]. In the SM, however, one assumes that effects of gravity can be neglected, because the scale where such effects become large is the Planck Scale. The question of why the 4-dimensional Planck Scale,  $G_{Pl}^{-1/2} \sim 10^{19} \text{ GeV}$ , is much larger than the electroweak (EWK) scale,  $G_{\mathcal{F}}^{-1/2} \sim 10^2 \text{ GeV}$ , is an outstanding problem in contemporary physics. Motivated in part by naturalness issues, numerous scenarios have emerged recently, that address the hierarchy problem within the context of the old idea that some part of the physical world (i.e. the SM-world) is confined to a brane in a higher dimensional space [3]. As we don't experience more than 3 spatial dimensions, we have to assume that any possible Extra Spatial Dimension (*ESD*) is hidden i.e. compactified. The impact of virtual gravitons in hadron collider experiments can be observed in processes such as:  $q\bar{q} \rightarrow G \rightarrow \gamma\gamma$  or  $g\bar{g} \rightarrow G \rightarrow e^+e^-$  where the ADD model introduces production mechanism that can increase the cross-section of diphoton and di-electron production at high invariant mass over the SM. The diphoton and di-electron cross-section considering the Large Extra Dimension (*LED*) contributions take the form [4]:

$$\frac{d^2\sigma_{Tot}}{d\cos\theta^* dM} = \frac{d^2\sigma_{SM}}{d\cos\theta^* dM} + \frac{a(n)}{M_{\mathcal{F}}^4} F_1(\cos\theta^*, M) + \frac{b(n)}{M_{\mathcal{F}}^8} F_2(\cos\theta^*, M) \quad (1)$$

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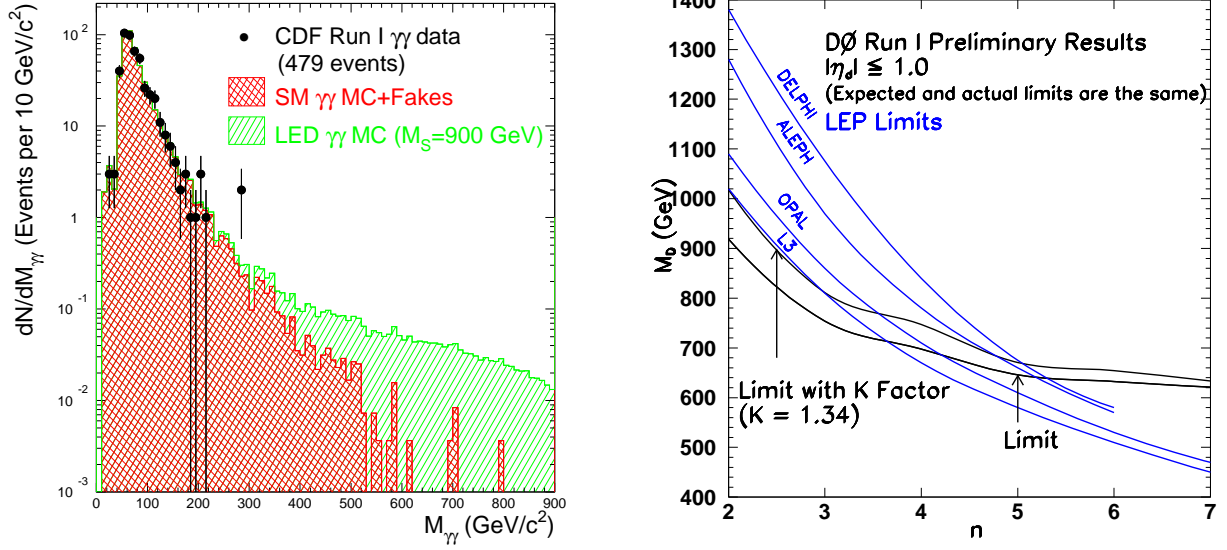


Figure 1: a) CDF Diphoton invariant mass distribution for data (dots), SM  $\gamma\gamma$  + fake (red area) and for the LED  $\gamma\gamma$  MC ( $M_S=900$  GeV); b) 95% C.L. lower limits on  $M_D$  in the DØ search for real graviton emission.

where  $\cos\theta^*$  is the scattering angle of  $\gamma$  or  $e$  in the center of mass frame of the incoming parton. The first term in the expression 1 is the pure SM contribution to the cross section; the second and the third part are the interference term and the direct  $G_{KK}$  contribution. The characteristic signatures for contributions from virtual  $G_{KK}$  correspond to the formation of massive systems abnormally beyond the SM expectations. Figure 1.a shows a comparison of the diphoton invariant mass for signal, background processes and for the data. With no excess apparent beyond SM expectations CDF proceeds to calculate a lower limit on the graviton contribution to the di-electron, diphoton cross section. The limits are given in table 2 [5] and they are translated in the three canonical notations: Hewett, GRW and HLZ [6].

Sample	K	Hewett		GRW	HLZ				
		$\lambda=-1$	$\lambda=+1$		$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
CC+CP $\gamma\gamma$	1.0	899	797	1006	1197	1006	909	846	800
$e^+e^-$	1.0	780	768	873	1038	873	789	734	694
$e^+e^-+\gamma\gamma$	1.0	905	826	1013	1205	1013	916	852	806
$e^+e^-+\gamma\gamma$	1.3	939	853	1051	1250	1051	950	884	836

Table 1: CDF 95% C.L. limit on the size of  $M_S$  for  $ee$ ,  $\gamma\gamma$  and combined channels. Combined results ( $e^+e^-+\gamma\gamma$ ) have been determined for both  $K = 1.0$  and  $K = 1.3$ .

Both CDF and DØ Collaborations at the Fermilab looked also for direct graviton emission. From an experimental point of view the mono-jet plus missing- $E_T$  signature is quite complex to study because of the large instrumental background from jet mismeasurement and the presence of cosmic rays background. The DØ 95% C.L. limit on  $M_D$  is given in Fig. 2.b.

### 3 Leptoquarks

Leptoquarks (LQ) are predicted in many extensions of the SM such as: Grand Unified Theories, Technicolor, etc. At Tevatron they can be pair produced through strong interactions:  $p\bar{p} \rightarrow$

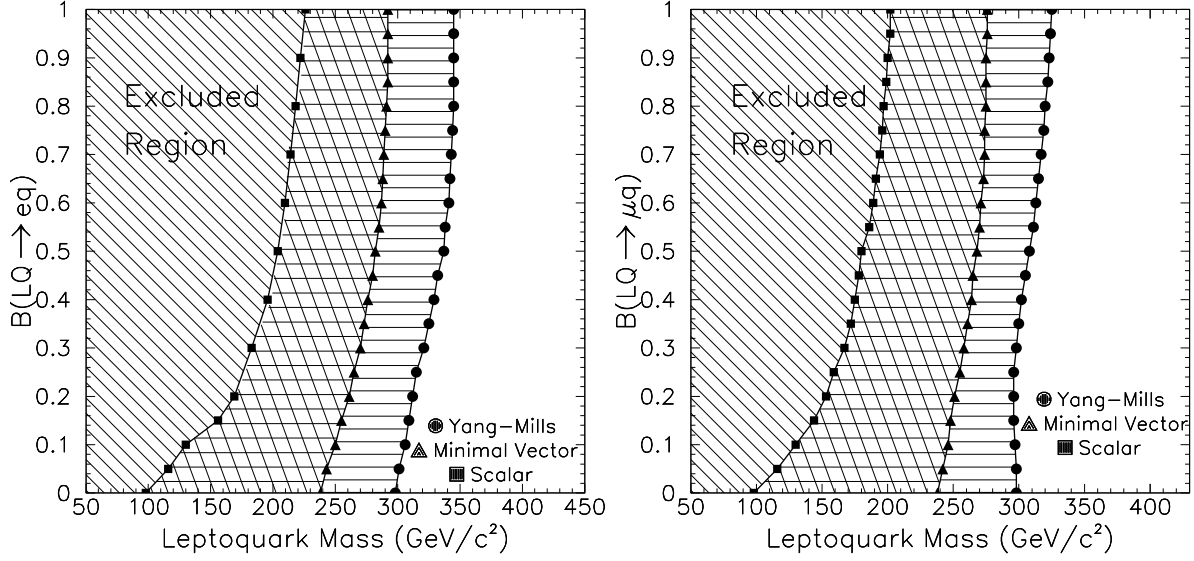


Figure 2:  $D\bar{O}$  combined 95% C.L. limit on the mass of scalar leptoquarks as a function of  $BR(LQ \rightarrow l^\pm q)$ ; a) for Scalar leptoquarks and b) for Vector leptoquarks.

$\bar{L}QLQ + X$  and decay in one of the following final states:  $\ell^\pm \ell^\mp q \bar{q}$  and  $\ell^\pm \nu q \bar{q}$  and  $\nu \bar{\nu} q \bar{q}$ . Both Tevatron experiments searched in the past for  $LQ$  by looking at final states containing one or two leptons [8, 7]. Here we report the latest  $D\bar{O}$  analysis performed by looking at the channel  $\nu \bar{\nu} q \bar{q}$ . The main sources of background for this process are SM multijet,  $W$ +Jets,  $Z$ +jets and  $t\bar{t}$  processes. Fig. 2.a and 2.b show the 95% C.L. limit obtained combining the present analysis with the previous  $D\bar{O}$  searches for both scalar and vector Leptoquarks.

## 4 Model independent probes

Until the number of compelling candidate theories of the *Nature* was small, it was natural to try to rule out each theoretical scenario, by finding observables that could truly help do differ SM processes from what expected from the specific model under investigation. Unfortunately, because of the complexity of the models, the increasing number, as well as the large parameter space that very often have to be considered for each of them, to follow a classical approach may not be an economic way to investigate the nature. In the past years the  $D0$  collaboration explored different approaches to the data analysis and come out with two useful tools: SLEUTH and then QUAERO.

SLEUTH is a quasi-model-independent search strategy for new high  $P_T$  physics. Given a data sample, its final state and a set of variables to that final state (see table 2), SLEUTH determines the most interesting region in those variables and quantifies the degree of interest. The published results are available in the Ref. [9].

QUAERO is a method that enables the automatic optimization of searches for physics beyond the SM, providing a tool for making the data available to a larger public (<http://quaero.fnal.gov>). QUAERO have been used in eleven separate searches such as leptoquark production:  $LQL\bar{Q} \rightarrow ee2j$ ,  $W'$  and  $Z'$  production:  $W' \rightarrow WZ \rightarrow e\cancel{E}_T2j$ ,  $Z' \rightarrow t\bar{t} \rightarrow e\cancel{E}_T4j$  and SM higgs production:  $h \rightarrow WW \rightarrow e\cancel{E}_T2j$ ,  $h \rightarrow ZZ \rightarrow ee2j$ ,  $Wh \rightarrow e\cancel{E}_T2j$ , and  $Zh \rightarrow ee2j$ . See Ref. [10].

Final state	Considered variable
$\cancel{E}_T$	$\cancel{E}_T$
$\geq 1$ Charged Leptons	$\sum p_T^\ell$
$\geq 1$ Vector Bosons	$\sum p_T^{\gamma/W/Z}$
$\geq 1$ jets	$\sum' p_T^j$

Table 2: A quasi-model-independently motivated list of interesting variables for any final state. The set of variables to consider for any particular final state is the union of the variables in the second column for each row that pertains to that final state.

## 5 Conclusions

We presented a sample of the latest results on physics beyond the SM at Tevatron. At present both CDF and DØ are collecting data with upgraded detectors challenging the Tevatron performances. With increase in luminosity and with present improved detector performances we expect these results to be greatly extended.

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